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Research Article

Application of material recovery facility (MRF) model in the context of community-based waste management – A study in Cham Island, Hoi An City, Vietnam

Song Toan PHAM PHU[1*], Cuong LE DINH[2], Quynh Nguyen MY[3]

[1]The University of Danang – University of Technology and Education, Faculty of Chemical Technology – Environment, 48 Cao Thang Street, Hai Chau district, Danang City, 550000, Vietnam
[2]The University of Danang - University of Technology and Education, Center for Environment and Life Science, 48 Cao Thang Street, Hai Chau district, Danang City, 550000, Vietnam
[3]World Wide Fund For Nature (WWF) Vietnam, No. 6, Lane 18 Nguyen Co Thach Street, Nam Tu Liem Dist, Ha Noi City, 100000, Vietnam

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ABSTRACT

This study aimed to assess the impact of material recovery facility (MRF) in dealing with problems of solid waste management systems, reducing solid waste generation, and raising awareness among residents in Cu Lao Cham island (CLC). Additionally, perception of islanders toward operation and development of MRF was also assessed. Literature review was conducted to have general understanding on status of MRF operation. Waste flow analysis was performed to illustrate waste flow of MRF by scenarios. In-depth interviews, observation, and questionnaire survey were applied to gain deep social insights into operation and potential for expansion of MRF. The results denoted that MRF recovered 51.41 kg of solid waste per day, accounting for 1.75% of the total MSW generated from households in CLC. Products from MRF, environmental effectiveness, the effectiveness of education and information publicity, and social cooperation had statistically significant effects on the participation of habitants in the operation and development of MRF. The MRFs will reduce 5.5% and 16% of the total domestic waste to Eo Gio in 2025 and 2028. The MRF was expected to attain financial independence from around 2025. Results from this study were scientific bases for managers, planners, policy-makers and other stakeholders for management and development of MRF not only in CLC but also other islands in developing countries.

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INTRODUCTION

Community-based waste management (CBWM) programs can be understood as collaborations between non-governmental organizations (NGOs), government agencies, and impacted communities to establish effective local waste management programs in which Indigenous communities play a key role in operating these programs effectively and independently [1, 2]. The CBWM is expected to solve the problems and challenges of solid waste management in lower- and middle-income countries, enhancing sustainability development and community empowerment. The advantages of CBWM would be listed as enhancement of community-member engagement and accountability, inspecting waste collection and reduction, household waste segregation, on-site utilization of valuable and reusable items, composting

***Corresponding author.**
*E-mail address: ppstoan@gmail.com

biodegradable waste, and public collection service to collect and transport waste. The model of CBWM has also contributed to effective operation of solid waste management systems in the Philippines [3] and Thailand [4].

Material recovery facility (MRF) — operated by the local community — has been becoming a popular model of CBWM in lower and middle-income countries such as Indonesia [5] and India [6]. In general, MRF is defined as a facility capable of temporarily storing solid waste and preparing it for classifying and cleaning recyclable waste. This will be considered a start for the nascent recyclable waste cycle [7]. The MRF also has larger potential for greenhouse gas mitigation compared with existing waste-to-energy plants [8].

The application of MRF would vary due to the characteristics of local areas. In the world, one of the most popular models of community-driven material recovery facility (CdMRF) is the "waste bank programs (WBP)" which was first researched in 2008 in Thailand [9]). In Thailand, the operators of WBP play an intermediate role in trading sorted recyclable waste for greater net revenues. WBP operation is normally conducted based on collaboration between waste generators and other stakeholders who agreed to store recyclable waste at facilities such as schools or public spaces [10]. Similarly, in Indonesia, WBP is cooperated by indigenous communities or local leaders from the surrounding area. Households joined in WBP must separate waste at their source and designated places [11]. At MRF, weighing and value evaluation of recyclable waste are conducted based on waste types and quality. Recyclable waste collected by the community is weighed and valued according to the type and classification of the waste. Additionally, MRF can record all joined stakeholders' trading information, such as transactions and balances. Members of WBP can withdraw money from the system if the requirement for a minimum amount of cash is fulfilled [12]. In two municipalities of Chennai and Hyderabad, MRF — driven by community — would offer economic incentives and job opportunities for the informal sector — local scavengers. CBWM was implemented by establishing a CdMRF that provided financial incentives and employment opportunities for local scavengers. In these two cities, MRFs could be understood as small-to-medium collection points that enhance the role of the local community within the recycling system [6].

Cu Lao Cham Island (CLC) is a famous tourism destination in Hoi An city, Vietnam, being a UNESCO-designated World Biosphere Reverse since 2009. Despite positive economic development thanks to tourism activities, the environmental problem — rapid increase in solid waste generation — has become a notorious issue which has not been effectively solved by local government and related stakeholders. There have been solutions implemented by local government such as controlling daily number of tourists and banning single-use plastic, but these solutions have not effectively combated problems of expeditious solid waste generation.

Community-based solid waste management has been considered as proper concept for the conditions of islands and remote areas, where there have been a host of difficulties and challenges for solid waste management. Reduction, reuse, and recycle have been prioritized for solid waste management strategy in CLC, thus, MRF has been strongly encouraged and supported by the local government. MRF has been allowed for pilot implementation, aiming at alleviating problems relating to solid waste generation and reducing solid waste to final treatment. At final treatment, solid waste has been gathered without proper sanitary, causing a high risk of leaching solid waste — especially plastic waste — into the environment at CLC. Therefore, MRF has been expected as a solution for solid waste management but also facilities for promoting environmental awareness and education for indigenous inhabitants and tourists.

The establishment of MRF in CLC has been considered a typical CBWM for central Vietnam and the whole country. The MRF in Bai Ong was established and operated on April 1, 2021, dealing with household solid waste from 30 households. Through two times of expansion, solid waste from 120 households in Bai Ong has been collected and gathered at the MRF. In November 2022, the second MRF facility was established in Bai Huong, an isolated village in CLC, to promote the positive effects of the CBWM and household solid waste recycling rate at source.

Despite the initial success of MRF, the effectiveness of MRF operation was not quantitatively assessed as a base for expansion and development in the near future. Moreover, existing studies on MRF have not proposed comprehensive picture — regarding technical and social assessment — for operation of MRF in islands of developing countries. MRF is a community-based model for solid waste management, in that, it would be potential shortcoming if solely technical assessment was conducted, disregarding social survey of residential community. Thus, the comprehensive assessment — technical and social aspects — is an essential reference for effective management and planning of MRF and solid waste management system in not only CLC but also other islands in developing countries. Moreover, there will be also a need for modifications and planning for the development of MRF with robust scientific bases.

Thus, this study contributed to existing research gaps due to some points. Firstly, this study aimed to quantitatively assess the impact of MRF in dealing with problems of solid waste management systems, reducing solid waste generation, and raising awareness among residents in CLC island. Moreover, the adaptation and cooperation of the community and the feasibility of the operation and development of MRF were also assessed. The role and contribution of MRF to the solid waste management system were also analyzed. Finally, this study would be a valuable reference for establishing a solid waste management strategy policy and building an action plan for spreading the MRF model on not only CLC island but also other islands in developing countries.

MATERIALS AND METHODS

Data Collection

There were two main stages for data collection in this study.

Firstly, literature review — research papers, reports, governmental reports, and grey documents — was conducted to have the general picture of MRF operation in CLC as well as statistics for estimating waste flow analysis and economic assessment. Secondly, a field trip was conducted by the authors and survey team including well-trained investigators from The University of Danang – University of Technology and Education. The authors implemented observation — operation status, and in-depth interviews — with related stakeholders — to gain information about MRF operation, problems and challenges for the development of MRF as well as double check data of collected reports [16], being bases for analyzing and founding scenarios for developing MRF in CLC. Moreover, social data was also collected through a questionnaire survey — under support from survey team — to acquire the interaction status and opinions of the local community about the operation and development of MRF.

The MRF Concept and Scenarios of Community-Based Waste Management in Cu Lao Cham

Depending on the capacity, the MRF was designed and built on an area of 50 m2 to 100 m2. There are two MRFs in CLC (Figure 1). The first MRF was set up at Bai Ong village to collect solid waste from 120 households. The second one was established in Bai Huong's isolated village, which has about 90 households. The MRFs are made from prefabricated steel and recycled plastic panels to store machinery supplies and dry recyclable waste.

The strategy for improving and spreading the MRF model in CLC to 2028 was built in the MRF development scenarios in two periods. The period of 2024 – 2025 is the re-setting phase, which focuses on enhancing the existing MRF's performance and establishing one more MRF in Bai Ong village. The waste source is from households. In the second phase (2026 – 2028), the capacity of the MRF was assumed to increase by increasing the amount of waste sources from households, markets, and public areas. Therefore, the waste reduction rate of MRFs is expected to reach 5.5% and 16% by the end of 2025 and 2028, respectively.

Waste Flow Analysis

Material flow analysis (MFA) is commonly used in solid waste management [13-15], being an effective tool used to simulate the path of waste and analyze the waste management system. In this study, STAN2 software is the tool used to simulate the flow of solid waste in CLC.

Social Consensus Assessment

In-depth interview and observation

In-depth interview and observation were applied in this study to gain insights into status of management and operation of MRF [16, 17]. Government officers and other stakeholders relating to solid waste management and MRF management were interviewed to acquire general information on CLC's solid waste management. Moreover, the attitude and consensus of stakeholders toward the operation and development of MRF and environmental protection were also topics for interview. Specifically, the advantages, problems, challenges, and potentials of the operation and development of MRF — from stakeholders' points of view — were topics discussed during in-depth interviews. The role of stakeholders and willingness to cooperate in operating and developing MRF were also clarified.

Questionnaire Survey

A semi-structured questionnaire was conducted to collect quantitative and qualitative data from households in CLC. The latent variables and items were designed with the 7-point Likert scale for application to the PLS-SEM model, which was applied to understand the social context of MRF application. Data analysis was implemented basing on PLS-SEM algorithms [18-20].

Economic Evaluation

Cost-benefit analysis is a method of economic analysis of a project activity where the values of costs and benefits to society are considered [21-23]. Some basic economic parameters during MRF operation were collected and calculated. Moreover, return on investment (ROI) was also calculated to analyse economic feasibility of MRF foundation. Investment costs were not included.

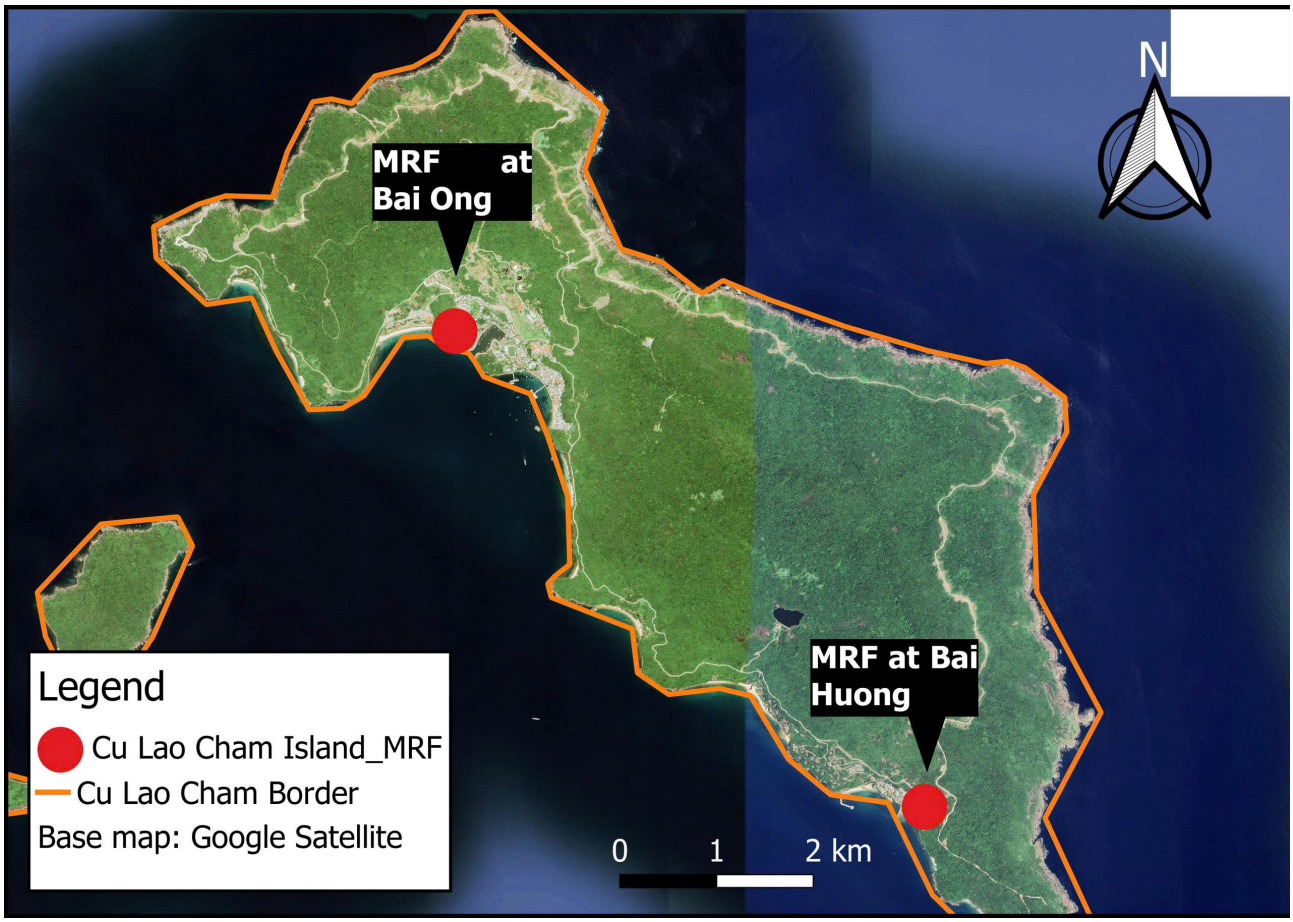

Figure 1. The location of the MRFs in Cu Lao Cham

Table 1. Assumptions of the MRF spreading scenario at CLC

Criteria	2023	Re-setting phase (2024 – 2025)	Spreading phase (2026 – 2028)
MSW generation (kg/d)	5,000	No change	Increased by 10% to 2028
Number of MRF	2	3	3
Waste sources:			
Number of household per MRF	120 - 90	120 – 120 - 90	150 – 120 - 90
Solid waste from Market to MRF	0%	0%	30%
Solid waste from Public area to MRF	0%	0%	50%
Solid waste reduction rate	1%	5.5%	16%

RESULTS AND DISCUSSIONS

Current Solid Waste Flow in CLC

Figure 2 shows that MRF recovered 51.41 kg of solid waste per day, accounting for 1.75% of the total MSW generated from the households. Specifically, Bai Ong MRF recovered and recycled 4.7% of the total MSW in the covered area, and Bai Huong MRF had the same efficiency of 4.2%. Two main MSW categories, biodegradable and dry recyclable solid waste (RSW), were recycled by 7.2% and 0.11% at Bai Ong MRF, 6.3% and 0.28% at Bai Huong MRF, respectively. This means that the MRF model initially showed positive signs when approaching and operating. However, compared to the operation of MRF in other countries such as Italy [24] and Canada [25], the amount of MSW recovered and recycled is still very limited.

The limitations of MRFs in CLC may be caused by the project's outreach to the community, and the community's doubts about the MRF model. This has also been proven to happen similarly in the pilot stages of applying the MRF model [26, 27].

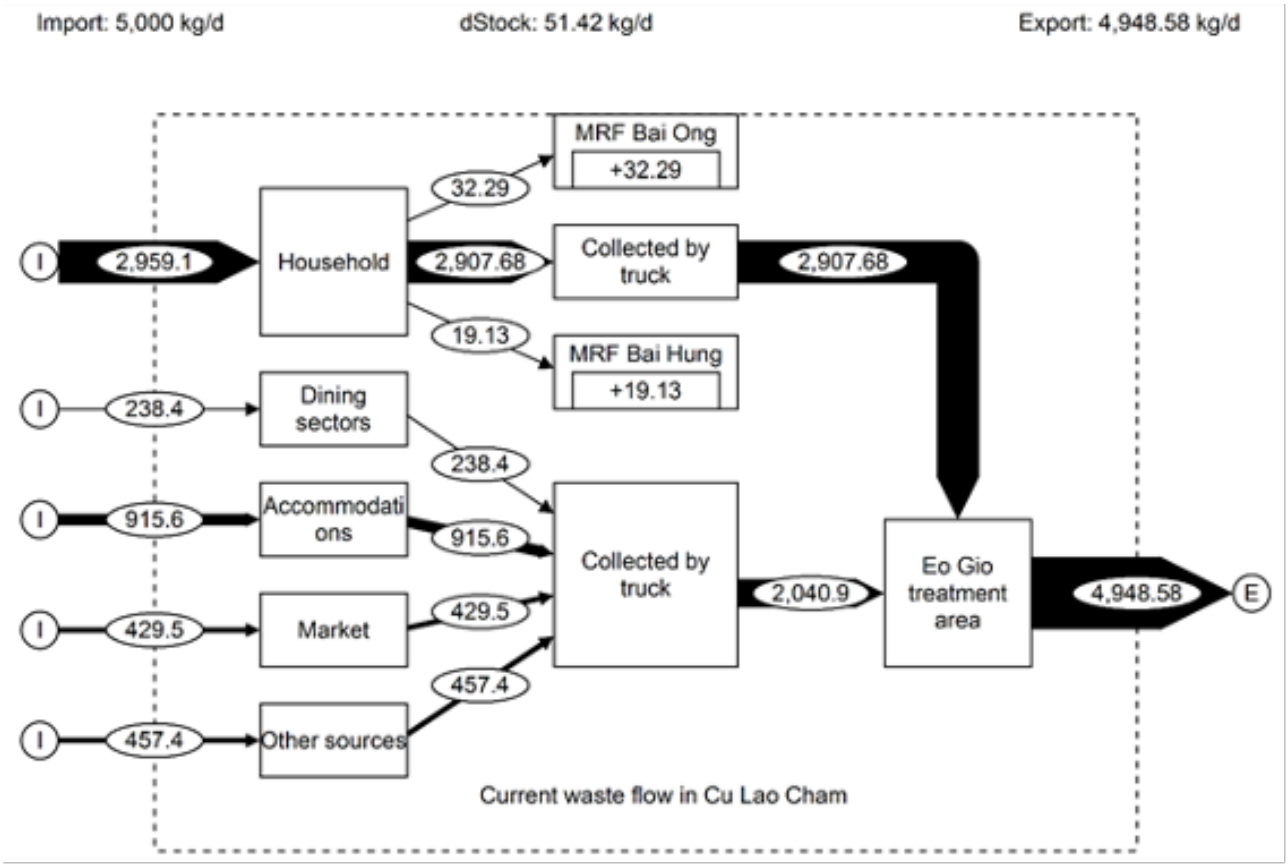

Figure 2. Waste flow in CLC

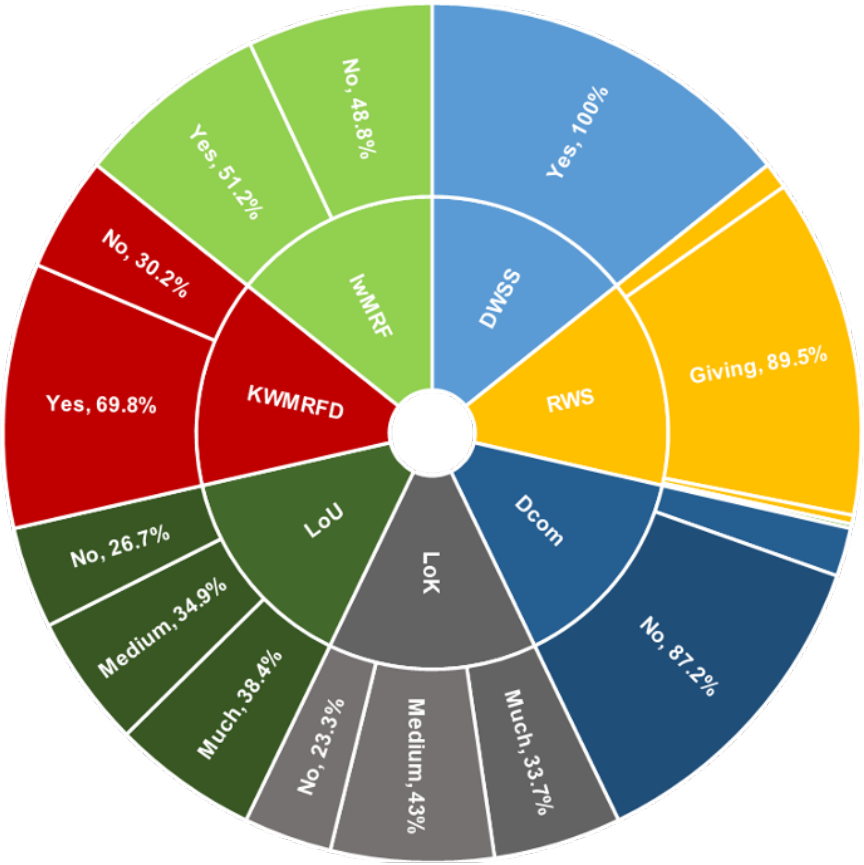

Figure 3. Interaction between local community and MRF (DWSS: Doing waste separation at source; RWS: Aim of separating recyclable waste; Dcom: Doing composting at home; LoK: General knowing level about MRF; LoU; Level of understanding what is MRF; KWMRFD: Knowing what MRF is doing; IwMRF: Interating with MRF.)

Social Acceptance

This study implemented a social survey for analysing social acceptance toward MRF in CLC, Hoi An city. Results of the social survey for interaction between indigenous inhabitants and MRF are illustrated in Fig 3. All participants were doing solid waste separation at source while only one per cent of surveyed people brought recyclable waste to MRF. The majority of participants (89.5%) have transferred recyclable waste to itinerant buyers or waste workers. These results denoted that MRFs, until now, have not been prioritised as final destinations for recyclable waste from households.

Regarding knowledge, understanding, and interaction with MRF, 23.3% of participants acknowledged no information on MRF while 43% of surveyed local people engaged in passive information reception about MRF. Importantly, 26.7% of participants showed an absence of understanding of the existence of MRF and operation while 30.2% of respondents had no understanding of the activities of MRF. Nearly half of the surveyed inhabitants (48.8%) had not previously visited MRF at CLC. It is undeniable role of the local community in the effective operation and development of MRF. Therefore, the existing status of interaction between local people and MRF should be strongly enhanced so that the operation and development of MRF would be strongly enhanced in the future.

Moreover, PLS-SEM model was also utilised to identify factors contributing to the effective operation and development of MRFs in CLC. To be specific, products from MRF, environmental effectiveness, the effectiveness of education and information publicity, and social cooperation had statistically significant effects on the participation of habitants in the operation and development of MRF (Fig 4). Moreover, acceptance from the community plays a key role in not only the operation and development of MRF but also solid waste management [28]. Thus, regarding products from MRF, increasing the quality of products from MRF, optimizing the proper prices of products, officially verifying quality of products from MRF would have direct effect on public participation on operation and development of MRF, contributing to enhancement of solid waste management system of CLC. Importantly, CLC is a tourism destination of not only Hoi An city but also central Vietnam, in that, environmental effectiveness of MRF would be a factor enhancing eco-tourism, being indirectly boosting community participation in operation and development of MRF. Additionally, social survey denoted statistical correlation between social cooperation as well as operating and developing MRF (Figure 4). Therefore, collecting community's opinions should be carefully implemented, being bases for planning and design of MRF.

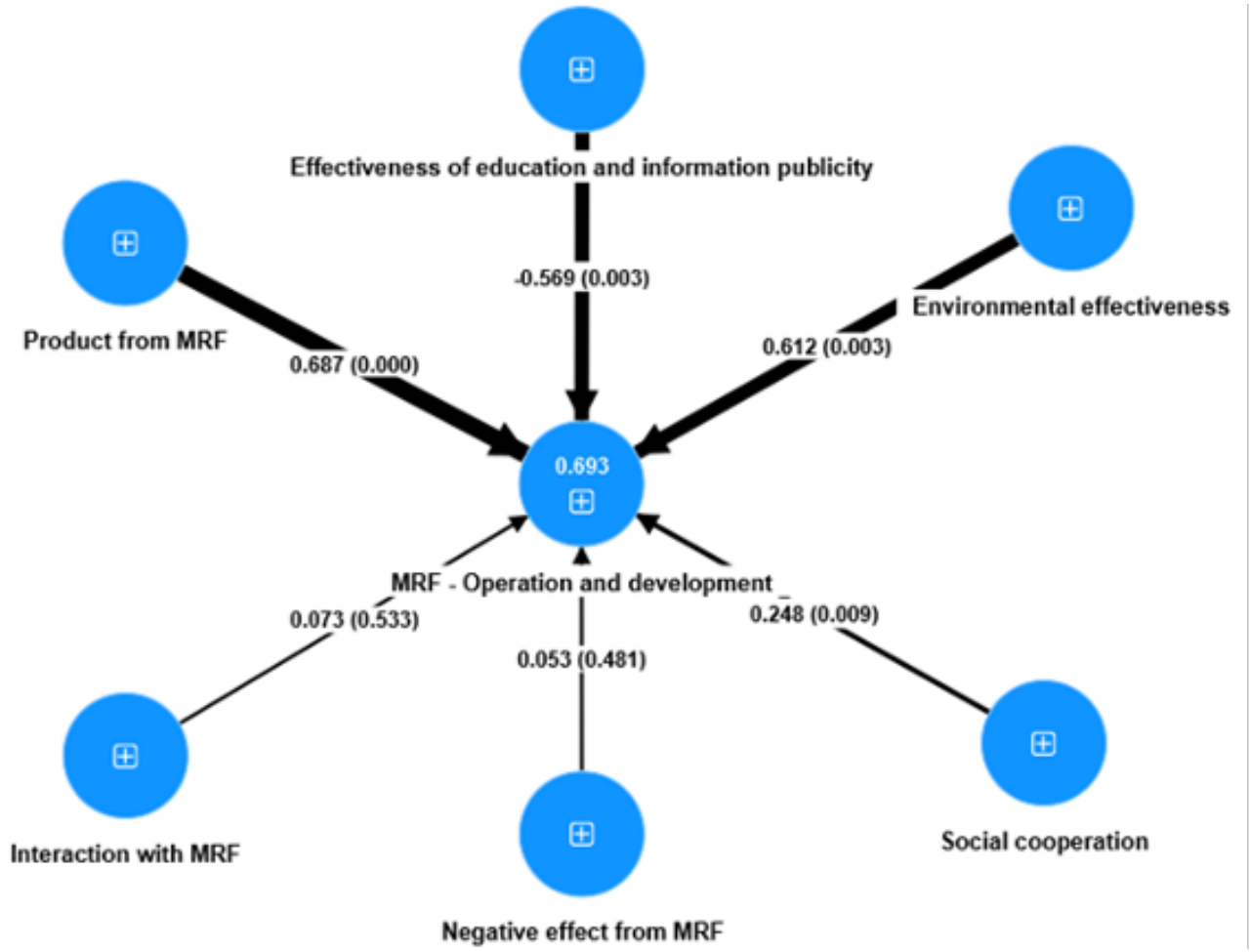

Figure 4. Factors affecting the operation and development of MRF

This study also revealed that propaganda and media activities had a statistically negative correlation to attitudes in the MRF operation process (p-value = 0.003, β-value = -0.569) (Fig 4). This would indicate the low efficiency of MRF-related environmental education and communication campaigns. Currently, the communities also have negative feedback on the role of MRF in raising environmental awareness among the residents and promoting eco-tourism. Thus, due to importance of environmental education and communication campaigns for pro-environmental behaviour [29], propaganda and media activities should be paid appropriate attention to encourage support from local people in the operation and development of MRF in CLC. Moreover, economic affordability should be considered in the MRF development strategy. Despite the importance of initial support from government or NGOs for foundations of MRFs, sustainable operation of MRFs is normally basing on financial conditions [30]. Thus financial sustainability for MRF should be considered through balance between product prices and operation costs of MRF.

As a result, due to results of social survey, products from MRF, environmental effectiveness, social cooperation, and effectiveness in education and information publicity were key factors, contributing to success of operation and development of MRFs in CLC, Hoi An city.

Analysis of Spreading MRF Model on Cu Lao Cham

Solid waste is collected by collection crews and gathered at the MRF. There are three types of waste collected separately: RSW (paper, plastic, and metal), BSW, and others. The other solid waste is transported to Eo Gio treatment facility by truck. BSW will be recycled by composting at MRF. RSW is cleaned, reduced in volume, and bagged to transfer to the junk shops. The operation of MRF in CLC is similar to other developing countries [30] with a focus on the recycling of BSW and RSW, while MRFs in developed countries are mainly for RSW processing [31, 32].

Figure 5 shows that the amount of MSW recovered by MRFs is estimated to increase in the next five years, with the BSW recovering efficiency reaching 20% in Phase 1 and rising to 30% in Phase 2. Besides, RSW is also estimated to increase the recovery rate to 2% (2025) and 4% in 2028. The MRF in Bai Huong is expected to recover better with a higher ratio, with BSW 30-50% and RSW 5-7%. The MRFs will reduce 5.5% and 16% of the total domestic waste to Eo Gio in 2025 and 2028, respectively. This development and spreading process is similar to that encountered at MRF facilities in other countries [33]. Additionally, the MRF reduces the biodegradable component in the MSW, contributes to reducing the moisture content, and increases the heating value, creating favourable conditions for incineration.

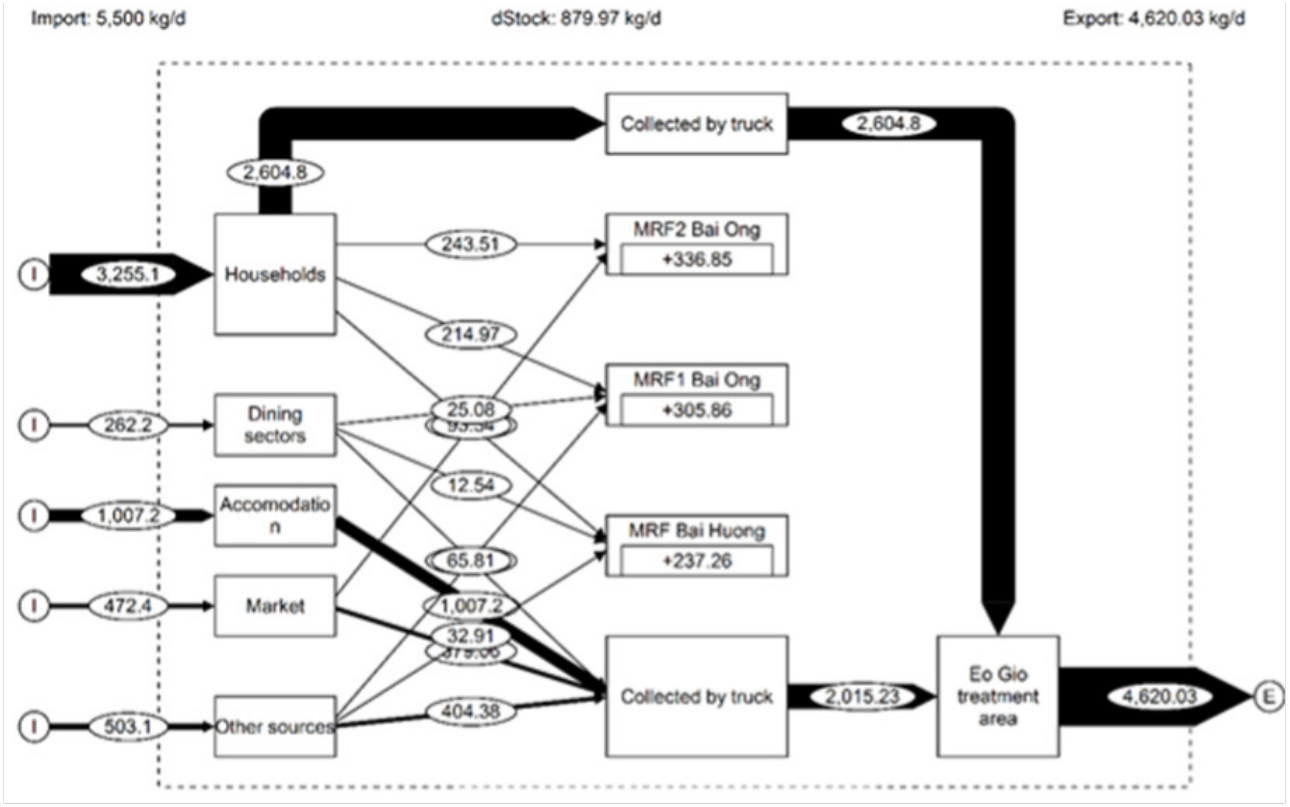

Figure 5. Estimation of the waste flow in Cu Lao Cham in 2028

To ensure the effectiveness of spreading the MRF model, technical and socio-economic factors need to be considered. This means the location of the MRF needs to be considered to optimize community engagement; the private-public partnership and participation should be encouraged; the awareness and knowledge on waste management at source should be improved, and the markets for recycled products from MRF should also promoted synchronously.

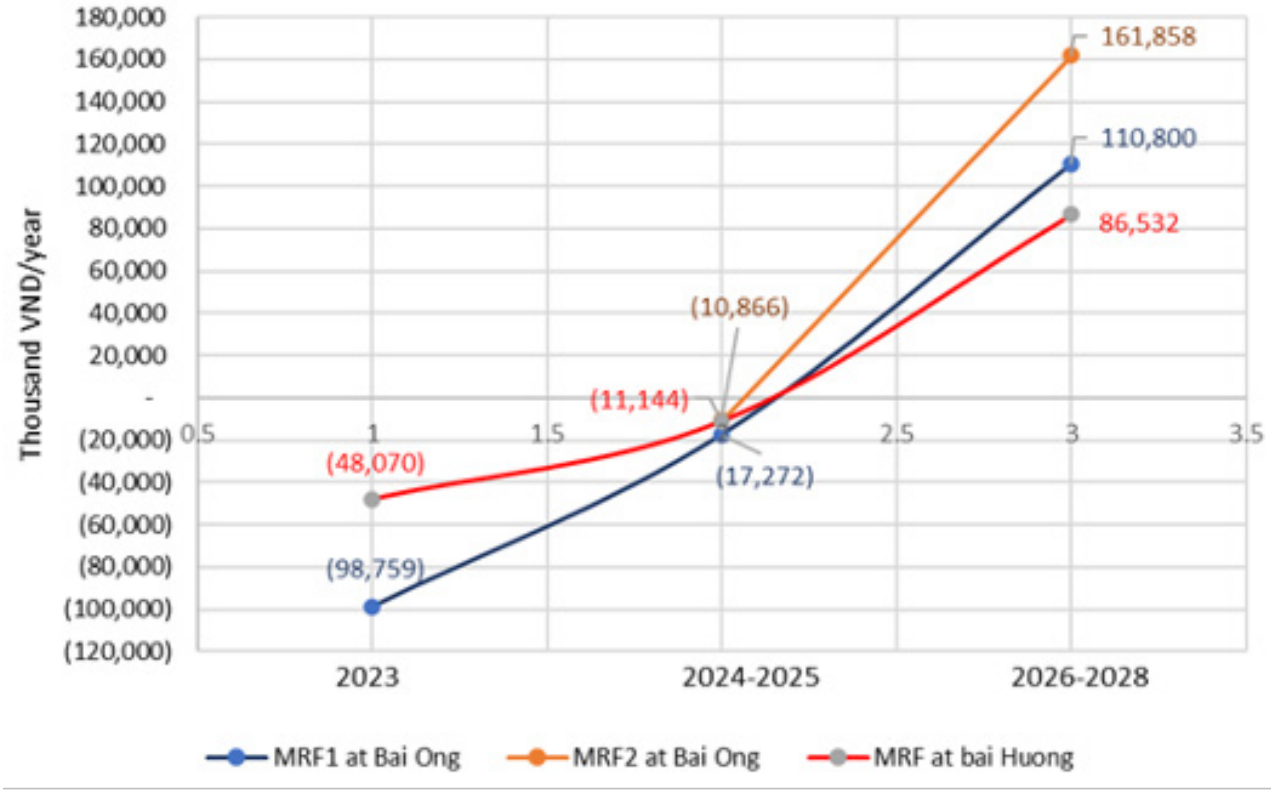

Figure 6. Estimation of the MRF's net benefit in CLC

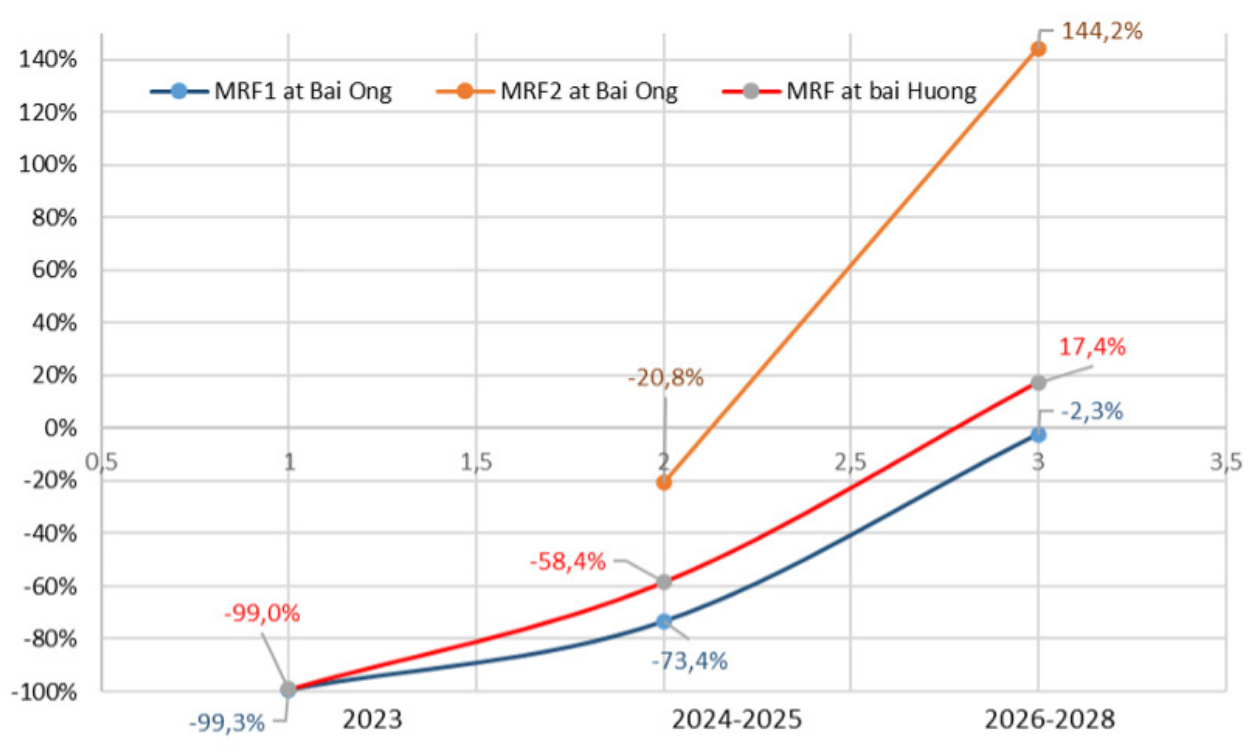

Figure 7. Estimation of MRF's return on investment (ROI) in Cu Lao Cham Island

Economic Affordability

In microview, this study indicated that MRF can finance its operations based on improving recycling activities. In 2023, the net benefit and ROI of the MRFs are negative (Figure 6-7). Based on the re-setting of MRFs, the improvement of recycling activities, collection areas, and communication activities is expected to improve the efficiency of recycling activities and the commercialization of products from MRFs. Assuming that during the re-setting phase, 50% of compost and bio-detergent products being traded at the cost of 5000 VND/L (or kg) would have helped reduce the fund by 5-7 times compared to the current. Thus, MRF can gradually move toward financial independence.

In the spreading phase (2026-2028), the recovery of coconut shells and BSW from the recycling market also contributes to the increase of recycling output. Enhancing product quality and communication activities is expected to increase the commercialization efficiency of recycled products from 50% to 70% during this phase. Commercializing recycled products is essential for the net benefit value of operating the MRF to be positive. Figure 6 indicates that the net benefit of MRF can reach 161 million VND/year in 2028. Moreover, values of ROI can also reach 144.2% (MRF2 at Bai Ong) and 17.4% (MRF at Bai Huong) in the same year (Figure 7). Economic affordability is a key factor affecting MRF model development [34, 35]. Synchronization in technical improvement activities and optimal community participation are the foundation. Strengthening communication activities, developing educational activities, and training skills to increase community proactiveness in interacting with MRF are long-term and continuous strategies that need to be clearly built. This has been indicated through the operation and development of MRF in other developing countries [5, 6].

CONCLUSION

This study indicated that MRF model is a highlight in SWM activities in CLC. Although there are still limitations in operating efficiency in the pilot phase, the potential to improve and spread the MRF model in CLC is proven to be feasible. Solid waste classification activities have been deployed and effectively implemented, serving as the foundation for waste recovery and recycling activities at the MRFs and the centralized treatment area. Technical upgrading and improving the effectiveness of community interaction in the re-setting and spreading phases will reduce 5.5% and 16% of the total solid waste to Eo Gio in 2025 and 2028, respectively.

In addition, this study has also demonstrated the feasibility of the self-sustaining ability of MRFs in Cu Lao Cham, as well as the effectiveness and suitability of the community-based waste management model of which MRF is a critical element. To be specific, quality of product from MRF, environmental effectiveness, and social acceptance were significant factors contributing to the operation and development of MRF.

This study offered scientific basis for pilot research and replication of the MRF model in rural or island communities and further research for urban communities.

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DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

The survey was informed to the local government. This study followed strictly all procedures to protect the personal information of participants. Before answering questions or presenting opinions, informed consent was collected by survey team. Participants were also informed about the background of the study and the purpose of this survey. Moreover, participants were also informed that data will be only used for research purposes and personal information will be strictly protected. The participation of people will be based on their free will. Participants have the right to quit the survey or not answer questions without any explanation. Moreover, this survey did not collect sensitive personal information such as name and signature.

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